Issued September 9, 1907.

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF SOILS—BULLETIN No. 45.

MILTON WHITNEY, Chief.

THE MOISTURE EQUIVALENTS OF SOILS.

BY

LYMAN J. BRIGGS AND JOHN W. McLANE.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1907.

BUREAU OF SOILS.

Milton Whitney, *Chief of Bureau.*
Albert G. Rice, *Chief Clerk.*

SCIENTIFIC STAFF.

Frank K. Cameron, in charge of Soil Laboratories.
Frank D. Gardner, in charge of Soil Management.
George T. McNess, in charge of Tobacco Investigations.
Clarence W. Dorsey, in charge of Alkali Land Reclamation.
Jay A. Bonsteel, in charge of Soil Survey.
Oswald Schreiner, in charge of Fertility Investigations.
W J McGee, in charge of Soil Erosion Investigations.

Issued September 9, 1907.

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF SOILS—BULLETIN No. 45.

MILTON WHITNEY, Chief.

THE MOISTURE EQUIVALENTS OF SOILS.

BY

LYMAN J. BRIGGS AND JOHN W. McLANE.

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1907.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., May 8, 1907.

Sir: I respectfully transmit herewith a technical report, entitled "The Moisture Equivalents of Soils," prepared by Messrs. Lyman J. Briggs and John W. McLane, formerly of the Physical Laboratory of this Bureau. This paper covers work done during their connection with this office, and I recommend that it be published as Bulletin No. 45 of the Bureau of Soils.

Respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

CONTENTS.

ILLUSTRATIONS.

PLATE.

TEXT FIGURE.

THE MOISTURE EQUIVALENTS OF SOILS.

INTRODUCTION.

It is important in the comparative study of soils that the mechanical composition, which forms the basis of most comparisons of this kind, shall be supplemented by the quantitative measurement of other characteristics, such as the moisture retentivity and the rate of capillary movement of water under standard conditions.

The measurement of the water-holding capacity under the action of gravity does not furnish a satisfactory method for comparing soils in a quantitative way, as such determinations are dependent upon the percentage of interstitial space in the soil, which in its turn depends upon the way in which the soil has been manipulated. It occurred to the authors that a satisfactory basis of comparison might, however, be established by determining the amount of water which different soils are capable of retaining when the moisture in the soil is subjected to a constant measured force, *sufficient in magnitude to remove the water held in the larger capillary spaces.* This may be easily done by placing the moist soils in suitable perforated cups and subjecting the soil moisture to centrifugal force. The magnitude of the force employed can be readily calculated by determining the radius of rotation and the speed.

MOISTURE EQUIVALENTS.

The percentage of water retained by a soil, when the moisture content is reduced by means of a constant centrifugal force until it is brought into a state of capillary equilibrium with the applied force, we propose to designate by the term *moisture equivalent.* In a series of samples in which the moist soils are all in equilibrium with the same force, it logically follows that if these soils are placed in contact, each soil containing an amount of water equal to its moisture equivalent and the packing of each soil being the same as in the centrifugal machine, the soils will be in capillary equilibrium and no movement of water from one soil to another will take place. This conclusion has been verified experimentally. The packing to which each soil

is subjected in the centrifugal machine seems as nearly definite and reproducible as it is possible to obtain, since each element of mass at the same distance from the axis is subjected to the same centrifugal force. When a layer of soil of uniform thickness is employed, the conditions are practically the same for each soil examined. Consequently the determination of the moisture equivalents of a series of soils shows the amount of moisture each will retain when all are packed in a uniform manner and are subjected to the same centrifugal force.

DESCRIPTION OF CENTRIFUGAL MACHINE USED FOR DETERMINING MOISTURE EQUIVALENTS.

In designing apparatus for the determination of the moisture equivalents of soils the first requisite is a shaft with bearings capable of standing high shaft velocities without undue heating. To save expense various commercial machines were considered with a view to their adaptation to this purpose, and a grinding machine was finally secured as most nearly fulfilling the desired condition. The bearings did not, however, prove satisfactory, and it was only after special bronze bearings had been substituted and the shaft had been carefully ground that a speed of 5,000 revolutions per minute could be maintained without unsafe heating. The steam turbine, with the centrifugal apparatus mounted on, or directly connected to, the turbine shaft, is the ideal arrangement for high-speed machines of this class.

The machine as finally used is shown in Plate I, fig. 1, with the centrifugal head in position. The main shaft passes through the cylindrical head, which is secured in position by being clamped between two heavy flanges by means of a nut threaded on the shaft. The other end of the shaft was designed to take a centrifugal head of another form.[a] In the illustration, however, this end of the shaft simply carries a small worm which engages a gear wheel having 100 teeth. A small spur on the side of the gear wheel momentarily closes a circuit once each revolution, actuating a sounder in the engine room, and in this way the speed of the machine could be determined and kept nearly uniform by regulating the speed of the engine.

The construction of the centrifugal head is shown in Plate I, fig. 2.

[a] Such a machine is capable of serving a double purpose, since with another form of centrifugal head it can be used as a means of extracting and collecting from a moist soil a portion of its soil solution. The composition and concentration of the solution thus removed would appear to be identical with that in the soil from which the plant derives its mineral food, and the method seems a promising one for investigating the relation of the composition and concentration of the water-soluble constituents to the productivity of the soil.

The cylinder, which is of brass, is 24.7 cm. outside diameter, and the thickness of the cylindrical wall is 1.3 cm. Care was taken to secure a uniform, homogeneous casting, and both the cylinder and cover were accurately finished inside and out, which gave a perfectly balanced system. The cylinder carries in its interior eight brass cylindrical cups with fine gauze bottoms covered with thin disks of filter paper, in which the soils under investigation are placed. Each of these cups rests upon the flat surface of a cylindrical segment fitted to the inside of the centrifugal head. These segments are equally spaced about the interior of the cylinder and are held in position by screws. To keep the cups in position when the machine is at rest a brass diaphragm having apertures for each cup is fitted into the cylinder, as shown in the illustration. The cover is provided with a slightly tapered flange which fits snugly over the open end of the centrifugal head. The moisture removed from the samples works out through the joint between the head and the cover. Since the whole outer surface of the cylinder is accurately turned and smoothly finished, the air friction is reduced to a minimum.

While it is possible to examine eight samples of soil at one time with the machine as described, this procedure is apt to throw the machine out of balance, for the samples will in general lose different amounts of water during the test. Since duplicate determinations were desirable, four samples were run at one time. The cups containing the same sample were brought to equal weight and placed on diametrically opposite sides of the cylinder, which kept the machine in balance throughout the experiment.

This machine was normally driven at 5,000 revolutions per minute by means of a steam engine running at 300 revolutions. A belt from the fly wheel of the engine drove a shaft, to which the centrifugal machine was belted, at 2,000 revolutions per minute. The centrifugal machine and the pillow blocks carrying the end of the shaft opposite the machine were mounted on the same cement foundation, which rested upon a bed of sand and was free from the floor and walls of the building. This effectually prevented the machine from producing any serious vibration or jarring of the building.

It is an essential condition in the successful operation of all high-speed centrifugal machinery that the rotating system shall be as nearly perfectly balanced as possible. Machines which are not in perfect balance vibrate badly when the period of rotation corresponds to the natural period of vibration of the machine. This speed is sometimes spoken of by manufacturers of centrifugal apparatus as the "critical speed," above or below which the machine operates much more quietly.

The centrifugal force $\bar{f}$,[a] expressed in dynes, acting on an element of water, dm, is

$$f=4\ \pi^2\ n^2\ r.\ dm$$

where n is the number of revolutions of the apparatus per second and r is the distance of the element of water from the axis. Since the bottoms of diametrically opposite cups, when in position in the cylinder, were 21.5 cm. apart, we would have for a layer of soil 5 mm. in thickness, a mean radius of rotation of 10.5 cm. The centrifugal acceleration, i. e., the force acting on unit mass of water, corresponding to each of the different velocities employed in the following experiments, is given below (Table I). We can also express the centrifugal accelerations in terms of the acceleration of gravity as a unit, since the acceleration of gravity is equal to 980 dynes. To avoid confusion, the calculations in the table are given in terms of unit volume (1 cubic centimeter) of soil moisture, which is assumed to have unit mass. The second column gives the force in dynes, and the third column gives the force in terms of the force of gravity as a unit.

TABLE I.—*Centrifugal force acting on unit mass of soil moisture at the various speeds employed.*

Revolutions per minute.	Force, dynes per c. c.	Force, grams per c. c.
2,700	$839 \cdot 10^3$	857
3,000	1,036	1,057
3,200	1,179	1,203
4,100	1,936	1,975
4,200	2,031	2,073
4,300	2,129	2,174
5,000	2,878	2,937
5,500	3,483	3,554

EFFECT OF DURATION OF TEST ON THE MOISTURE EQUIVALENT.

In order to determine the time required to bring the moisture content of the samples into capillary equilibrium with the centrifugal force applied, a series of preliminary experiments (varying in duration from 15 to 60 minutes) was made upon several soil types. The results are given in Table II. The first column of the table gives the

[a] Some English writers object to the term "centrifugal force." The term has, however, so thoroughly established itself in this country and is so generally understood that it appears advisable to use it here. There is, of course, no actual force exerted in a centrifugal machine which tends to pull the water out of the soil. What actually occurs in the machine is just the opposite; that is to say, the soil is pulled away from the water. There is an acceleration of the soil directed inward toward the axis, which leaves the water behind. The result is, of course, the same as if the water were subject to an equal acceleration outward.

type of soil used, the second column gives the percentage of moisture remaining in the soil at the end of the test, and the third column gives the time during which the moisture in the sample was subjected to centrifugal force. It will be noted that there is a slight reduction in the moisture equivalent as the time increases in nearly every case, although this effect is small after a period of thirty minutes.

These determinations were made upon a thicker layer of soil than was employed in the final experiments, so a somewhat longer time was necessary to attain approximate equilibrium. Thirty minutes was accordingly decided upon for the duration of the tests in the final experiments. In some extremely heavy soils the moisture content might be slightly reduced by extending this period, since the distribution of moisture in a sample would probably reach a state of complete equilibrium only after a considerable interval had elapsed. Errors due to other causes, however, such as the fluctuation in the speed of the machine, did not appear to us to justify an attempt for further accuracy in this direction.

TABLE II.—*Effect of duration of test upon moisture equivalent.*

Soil type.	Moisture after test.	Duration of test.	Speed per minute.	Soil type.	Moisture after test.	Duration of test.	Speed per minute.
	Per cent.	*Minutes.*	*Revs.*		*Per cent.*	*Minutes.*	*Revs.*
Leonardtown loam.	14.9	15	4,800	9248 Hagerstown loam............	17.3	30	5,000
	14.6	15	4,800		17.2	45	5,000
	13.7	30	4,800		16.2	45	5,000
	13.1	30	4,800	9037 Hagerstown clay............	22.2	30	5,000
	13.3	45	4,800		21.9	30	5,000
	13.4	45	4,800		21.7	45	5,000
	13.0	60	4,800		21.4	45	5,000
	12.4	60	4,800	8589 Norfolk fine sand............	3.1	30	5,000
10212 Hagerstown silt loam.........	16.0	30	5,000		3.4	30	5,000
	15.7	30	5,000		3.1	45	5,000
	15.5	45	5,000		3.3	45	5,000
	15.2	45	5,000				
9248 Hagerstown loam..............	17.2	30	5,000				

EFFECT OF INITIAL WATER CONTENT ON THE MOISTURE EQUIVALENT.

A second series of experiments was made to determine whether the percentage of water used in moistening a soil had any influence upon the moisture equivalent, providing, of course, that the amount of water used was always greater than the soil could retain at the speed employed. It was thought that perhaps something akin to puddling might take place when relatively large amounts of water were used. Experiments were made with several different moisture contents in the case of each soil examined. One sample of each soil was saturated and another was puddled as much as possible by thorough mixing so as to accentuate the influence of the preliminary treatment of the soil upon the moisture equivalent. It will be noted from a comparison of the results, which are given in Table III,

that the initial moisture content in the case of the Leonardtown loam had very little influence upon the per cent of moisture remaining after the test. The same is true of the subsoil of the Norfolk sand. In the case of the subsoil of the Cecil clay, which is a heavy soil, the results show a gradual increase in the value of the moisture equivalent as the initial water content is increased, and the effect of puddling in this soil is marked, the percentage of water retained by the soil being increased from 32 to 39 per cent by the puddling process.

Therefore, in preparing the samples for a determination of the moisture equivalents, care was taken not to saturate the samples, and to stir the soil only enough to insure the distribution of the water throughout the sample.

Table III.—*Effect of initial water content on the moisture equivalent of soils.*

Soil type.	Approximate initial moisture content.	Moisture content after test.	Soil type.	Approximate initial moisture content.	Moisture content after test.
	Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
Leonardtown loam (good)	15	12.0	Norfolk sand (subsoil)	10	7.4
	15	12.1		10	7.3
	20	11.5		15	7.0
	20	10.9		15	7.1
	25	11.7		20	7.0
	25	11.8		20	7.0
	Puddled.	14.0		Puddled.	7.4
	Puddled.	11.7		Puddled.	7.3
	15	12.4	Cecil clay (subsoil)	35	32.9
	15	12.6		35	33.1
	20	11.4		40	34.1
	20	11.3		40	34.3
	25	11.8		43	35.0
	25	11.7		43	34.8
	Puddled.	11.9		Puddled.	39.2
	Puddled.	12.1		Puddled.	39.0

EFFECT OF SPEED ON THE MOISTURE EQUIVALENT.

A third series of measurements was made to determine for different soils the relation between the centrifugal force employed and the amount of moisture retained by the soils. If any definite and simple relation exists, then it would be possible to make the moisture equivalent determinations at any suitable speed and reduce the results to some standard condition, such as, for example, the retentivity of the soil when subjected to a force of 1,000 times the force of gravity. Such a relation would also enable us to calculate the amount of moisture which would become available when the pulling force is increased by a known amount.

The results of the experiments are given in Tables IV and V. In Table IV the different speeds employed are given at the heads of the columns, with duplicate determinations of the corresponding moisture equivalents below. The same arrangement exists in Table V, except that the means of the duplicate determinations are given. It will

be seen in Table IV that doubling the speed, which quadruples the centrifugal force, reduces the moisture content of the Dunesand only from 3.0 to 2.6 per cent. In the case of this sand the capillary spaces are relatively large in size and few in number, so that it seems probable that the lowest speed employed is sufficient to reduce the moisture content mainly to the form of a thin film on the surface of the soil grains, so that the effect of quadrupling the force is small. In all the other soils there is a well-defined and progressive decrease in the moisture content as the speed increases. The results of Table IV indicate that the Leonardtown loam, good, and the Leonardtown loam, poor, are distinctly different in their relation to moisture.[a] Sample No. 4983, in Table V, is seen also to differ from the other soils of the series, giving up its moisture much more readily with increasing speeds.

TABLE IV.—*Effect of speed on moisture equivalent.*

Soil type.	Revolutions per minute.											
	2,700.		3,000.		3,200.		4,100.		4,200.		5,500.	
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
New Mexico dunesand	3.0	3.0	2.9	2.7	2.9	3.0	2.9	2.7	2.6	2.6	2.7	2.6
Sassafras loam, good......	18.5	18.7	17.8	16.1	15.5	15.0	15.0	15.0	14.1	14.0	12.4	12.7
Leonardtown loam, good..	18.1	18.0	16.5	16.5	15.0	15.4	13.4	13.8	14.1	14.3	12.1	12.1
Leonardtown loam, poor..	12.0	12.0	10.1	10.5	9.4	9.9	8.0	7.5	7.4	7.4	6.3	6.3

TABLE V.—*Effect of speed upon the moisture equivalent.*

No.	Type.	Speed—revolutions per minute.		
		4,300.	5,000.	5,500.
		Per ct.	*Per ct.*	*Per ct.*
7233	Hagerstown stony loam..	16.9	15.0	14.6
6534	Hagerstown sandy loam..	12.2	11.0	9.9
4952	Hagerstown loam..	21.8	20.8	18.4
9248	Hagerstown loam..	18.3	17.5	16.5
10212	Hagerstown silt loam..	17.9	16.5	15.8
4983	Hagerstown shale loam..	31.6	25.0	17.3
4962	Hagerstown clay loam..	24.1	23.4	21.5
4966	Hagerstown clay loam..	26.0	25.5	24.8

A simpler way of comparing these results is to be found in the graphical arrangement shown in figure 1, for which we are indebted to Mr. Buckingham, of this laboratory. In this diagram the moisture equivalents are plotted as ordinates, while the abscissas are proportional to the reciprocal of the centrifugal force. If all of the moisture could be thrown out of the soil by an infinite centrifugal force, the moisture equivalent would be zero when the centrifugal force is infinite, i. e., when the reciprocal of the centrifugal force (plotted as abscissas) is zero. In this case all of the graphs would pass through the origin. However, between the limiting values of

[a] See Bulletin No. 22, Bureau of Soils, p. 34.

the centrifugal force employed in these experiments it will be seen that in nearly every case a *linear* relation exists between the moisture equivalent and the reciprocal of centrifugal force. These linear graphs when produced do not pass through the origin, but, on the other hand, *the slope of these graphs is in nearly every case the same.*

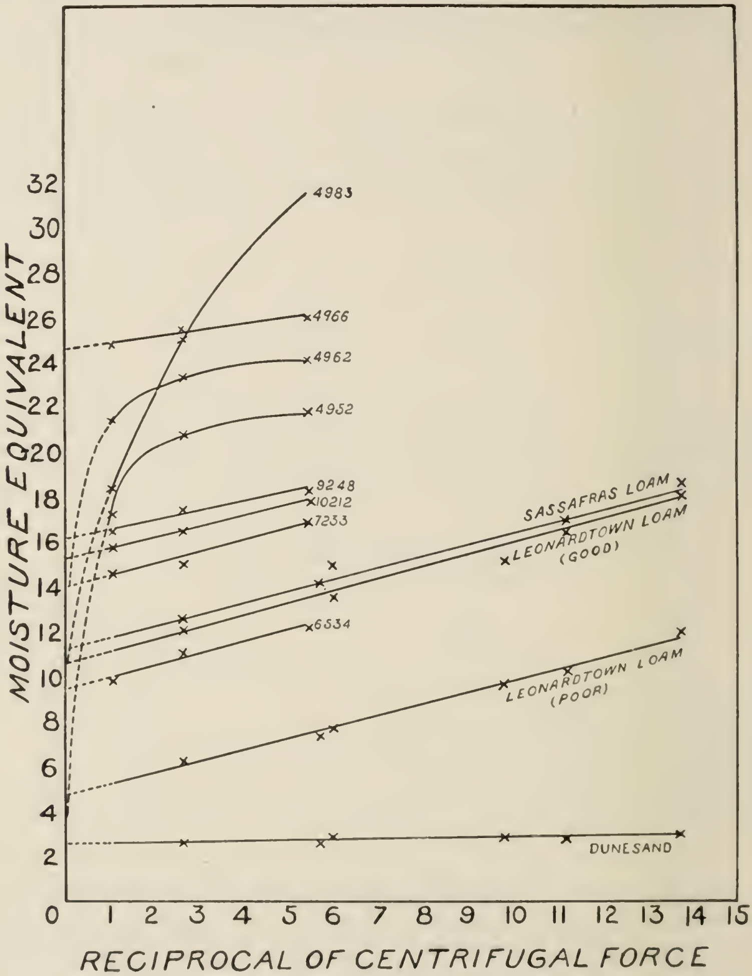

FIG. 1.—Relation of the moisture equivalent to the force employed.

Consequently we may represent within certain limits the relation between the moisture equivalent m and the centrifugal force f as follows:

$$m = m_0 + \frac{a}{f}$$

where m_0 is the intercept on the axis of ordinates of the prolongation of the linear part of the curve, and a is the slope. The constant

a may be computed from the data given in Table IV (the dunesand excepted), from which we get $a=6.100$, expressed in terms of the force of gravity. When a soil is in equilibrium with a force f_1, the amount of moisture which is liberated when the centrifugal force is increased from f_1 to f_2 is

$$m_1 - m_2 = a\ (\frac{1}{f_1} - \frac{1}{f_2})$$

or the moisture set free is proportional to the difference of the reciprocals of the two centrifugal forces, and *is independent of the initial moisture content.* For example, if $f_1=1.000$, $f_2=2.000$, $a=6,100$, then $m_1 - m_2=3.05$, or 3 per cent of water would be set free when the centrifugal force is increased from 1,000 to 2,000 times the force of gravity.

It must be distinctly understood that this relation has been tested for only a few soils, and that it can hold only between certain limits. It is evident from the diagram that the linear relation must fail at very high velocities. In fact, samples 4962 and 4952 show a marked tendency in this direction at the highest speed employed. At very low speeds, also, the linear relation no longer holds. The dunesand and sample 4983 are also exceptions, so far as a uniform value for the coefficient a is concerned. But even with such limitations this relation, if it is found to be applicable to other soils, will prove of value in adjusting moisture equivalents to a common basis, and in determining the amount of water available when the force is increased by a definite amount. The fact that the amount of water liberated from a soil in equilibrium with a given force, when the force is increased by a definite amount, is, between certain limits, independent of the initial moisture content, gives us a new point of view regarding the availability of the moisture of different soils.

These experiments have not been carried sufficiently far to reduce the moisture content of the soils to a point corresponding to drought conditions, but it appears doubtful from these experiments whether the linear relation would hold at speeds very much higher than these employed. The subject is worthy of extended investigation, especially at high velocities.

ACCURACY OF THE DETERMINATIONS OF THE MOISTURE EQUIVALENT.

The accuracy of the determinations of the moisture equivalents can best be judged from Table VI, in which is given a series of determinations made on different dates. It will be seen that a good agreement is generally obtained from different runs, the moisture equivalents usually agreeing within 0.5 per cent of moisture. Samples 8969 and 9332 show, however, a steady decrease in the moisture equivalents for successive determinations. The samples of these soils were small,

so that it was necessary to save the soil used in a determination of the moisture equivalent, for use in subsequent measurements. It is, therefore, possible that the repeated oven drying, which a part of the sample received, changed the character of the soil material sufficiently to produce the diminution of the moisture equivalent observed.

TABLE VI.—*Duplicate moisture equivalent determinations on different dates.*

[5,000 revolutions per minute.]

Sample No.	Type of soil.	First determination.	Second determination.
		Per ct.	*Per ct.*
9248	Hagerstown loam:		
	July 11	17.3	17.2
	Aug. 8	17.8	17.9
	Aug. 10	17.6	17.3
4962	Hagerstown clay loam:		
	Aug. 8	23.4	23.5
	Aug. 11	23.4	23.4
4966	Hagerstown clay loam:		
	July 12	24.9	24.9
	Aug. 8	26.5	26.2
	Aug. 11	25.6	25.3
8969	Miami stony loam:		
	July 18	17.7	15.9
	July 22	15.1	15.3
	Aug. 5	14.1	14.5
5008	Miami gravelly loam:		
	July 14	13.2	13.3
	July 20	13.5	13.6
5006	Miami loam:		
	July 20	17.7	17.7
	Aug. 7	18.0	18.0
	Aug. 9	17.5	17.8
8506	Miami silt loam:		
	July 15	18.3	18.7
8506	Miami silt loam—Contd.		
	July 20	18.3	18.5
	July 21	18.6	....
5014	Miami clay:		
	July 21	17.7	17.9
	Aug. 7	18.9	18.7
8398	Marshall sandy loam:		
	July 18	13.0	13.5
	July 22	13.3	13.6
9493	Marshall clay loam:		
	July 19	23.3	22.9
	July 21	23.4	....
9332	Oswego loam:		
	July 31	20.7	20.7
	Aug. 7	19.8	19.7
	Aug. 9	18.0	18.1
6917	Sedgwick clay loam:		
	July 28	21.3	22.2
	July 31	22.1	22.1
6632	Delavan silt loam:		
	Aug. 10	26.8	26.8
	Aug. 2	24.1	23.5
	Aug. 4	26.3	26.3

MOISTURE EQUIVALENTS OF TYPICAL SOILS.

With the experiments described in the foregoing pages as a basis, determinations were made under uniform conditions of the moisture equivalents of representative samples of each of the important soil types established by the Bureau. These determinations are given in Table VII, arranged in the form of correlated series, so far as these series have been established.

The determinations were all made at a speed of 5,000 revolutions per minute, which would correspond to a centrifugal acceleration equal to 2,940 times that of gravity. The determination of the speed was not accurate to more than 1 per cent, which means a variation of 2 per cent in the centrifugal force, since the speed enters as the square in the equation. The centrifugal force employed in these measurements would then be

$$f = (2940 \pm 60)\ g$$

where g represents the force of gravity.

The amount of soil used covered the bottom of the cylindrical cup (internal diameter 4.7 cm.) to a depth of approximately 5 mm.

When large amounts of soil were used, it was found in some of the more retentive soils that there was a tendency for a part of the water to accumulate upon the top of the soil instead of passing through the soil and escaping through the perforated bottom of the cup. No trouble was experienced in this way when the layer of soil did not exceed 0.5 cm. in thickness.

At the end of the run a moisture determination was made immediately of each sample of soil used in the test, the whole of the sample being employed for this purpose. The moist samples were quickly weighed and then dried for eight hours in an oven maintained at a temperature of 108° C., and then weighed again. Such a temperature in an oven is easily maintained by the use of toluol in the so-called water oven. If the apparatus is provided with a good Allihn return condenser, very little toluol escapes, and the apparatus works very satisfactorily.

In Table VII the first column following the type names gives the moisture equivalent; the second the percentage of organic matter, determined by the chromic acid combustion method; the remaining columns give the mechanical composition. The limits of the diameters of the particles in each group are given in italics under the group number.

TABLE VII.—*Moisture equivalents and mechanical composition of typical soils.*

No.	Type.	Moisture equivalent.	Organic matter.	(1) *2–1 mm.*	(2) *1–0.5 mm.*	(3) *0.5–0.25 mm.*	(4) *0.25–0.1 mm.*	(5) *0.1–0.05 mm.*	(6) *0.05–0.005 mm.*	(7) *0.005–0.0 mm.*
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
9107	Norfolk coarse sand	**4.6**	0.9	9.6	35.3	19.1	16.4	7.2	7.3	4.8
8522	Norfolk sand	**3.6**	1.0	2.0	8.5	19.0	52.6	7.1	5.8	4.7
8589	Norfolk fine sand	**3.8**	0.8	0.0	0.7	13.7	69.0	5.4	7.9	3.0
5665	Norfolk sandy loam	**6.5**	0.7	4.3	12.7	18.3	33.1	6.6	20.0	5.6
8706	Norfolk fine sandy loam	**6.8**	1.3	0.0	0.5	4.8	54.6	13.4	18.1	8.5
8682	Norfolk loam	**7.7**	1.9	0.3	8.9	16.2	16.7	5.4	42.5	9.7
5493	Norfolk silt loam	**11.1**	1.2	0.0	1.4	2.8	8.9	6.7	68.3	12.0
8530	Portsmouth sand	**7.1**	3.0	1.9	16.8	25.0	31.7	5.5	6.7	11.3
8537	Portsmouth sandy loam	**18.6**	10.9	0.8	4.9	7.3	31.7	13.0	23.6	18.7
10666	Portsmouth fine sandy loam	**11.8**	1.0	0.3	1.5	2.0	45.4	15.1	24.2	12.6
8022	Portsmouth loam	**19.6**	2.7	0.0	0.3	0.3	14.7	24.5	43.5	16.8
7848	Orangeburg sandy loam	**5.7**	1.7	9.5	20.8	13.3	22.7	15.4	6.4	11.6
8584	Orangeburg fine sandy loam	**3.2**	0.4	0.0	0.2	2.2	69.6	8.3	16.3	3.3
8339	Orangeburg clay (clay loam)	**21.4**	0.5	5.2	4.5	4.9	9.3	23.4	24.8	28.8
10087	Houston silt loam	**13.7**	1.7	1.0	1.2	1.0	5.8	15.1	63.4	12.3
10574	Houston black clay loam	**32.4**	3.7	0.3	0.6	0.8	12.1	17.1	42.5	26.6
7887	Houston clay (silty)	**22.5**	1.3	0.5	1.7	2.8	13.3	9.1	45.9	26.4
10083	Houston black clay	**38.2**	1.4	0.5	0.9	0.6	2.2	6.1	56.6	33.4
7753	Vernon sand	**3.6**	0.5	0.0	7.4	25.0	45.3	13.4	5.4	3.6
10118	Vernon fine sand	**4.3**	0.2	0.0	0.1	0.2	49.4	42.1	5.9	2.1
7757	Vernon sandy loam	**10.3**	0.8	0.2	8.8	17.9	25.6	22.8	13.2	11.3
7737	Vernon fine sandy loam	**12.3**	0.8	0.0	0.7	0.5	2.6	47.0	42.3	6.7
7749	Vernon silt loam	**19.8**	0.9	0.1	0.1	0.0	0.3	16.4	72.2	10.7
7763	Vernon clay (loam)	**23.1**	1.1	0.5	0.2	1.3	3.6	27.1	51.1	15.9
6442	Yazoo loam	**18.9**	1.3	0.3	0.9	0.7	3.7	19.9	64.1	10.1
6430	Yazoo clay	**31.7**	1.4	0.0	0.1	0.2	1.6	4.0	63.2	31.1
5741	Cecil sand	**5.1**	0.8	7.6	17.7	13.6	25.0	12.0	17.4	6.1
5327	Cecil sandy loam	**7.7**	1.2	14.7	15.6	9.8	21.3	13.1	17.8	7.9
7185	Cecil loam	**16.6**	1.9	1.9	5.1	4.8	15.3	9.6	39.6	23.6
4988	Cecil mica loam	**12.2**	1.9	7.8	4.3	2.2	14.4	30.9	33.3	7.8
5719	Cecil silt loam	**8.3**	0.6	2.6	1.7	0.7	3.4	6.1	74.2	11.8
5727	Cecil clay (clay loam)	**21.2**	2.0	1.4	2.7	2.0	7.1	10.1	44.8	31.6

TABLE VII.—*Moisture equivalents and mechanical composition of typical soils*—Continued.

No.	Type.	Moisture equivalent.	Organic matter.	(1) 2-1 mm.	(2) 1-0.5 mm.	(3) 0.5-0.25 mm.	(4) 0.25-0.1 mm.	(5) 0.1-0.05 mm.	(6) 0.05-0.005 mm.	(7) 0.005-0.0 mm.
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
5904	Penn sandy loam	9.3	0.9	2.2	11.6	13.4	27.6	11.8	21.0	12.1
5868	Penn loam	17.[illegible]	1.[illegible]	2.6	7.6	7.0	14.3	7.8	37.4	22.8
7703	Penn clay (clay loam)	17.9	1.3	1.4	2.7	2.1	5.0	14.0	42.6	32.2
7240	Dekalb stony loam	12.8	2.5	3.4	11.1	9.0	17.7	10.8	33.4	14.6
10025	Dekalb sandy loam	11.7	1.3	0.5	11.0	26.1	24.2	4.3	17.8	16.1
10216	Dekalb fine sandy loam	12.8	1.0	0.4	1.4	8.8	44.2	8.1	25.0	11.9
10154	Dekalb clay loam	21.6	2.3	0.4	0.7	2.1	6.6	14.8	48.6	26.9
7233	Hagerstown stony loam	15.0	1.6	2.7	4.9	3.6	7.3	14.1	45.1	22.1
6534	Hagerstown sandy loam	11.0	1.0	0.4	5.0	8.8	23.4	20.2	33.0	9.4
4952	Hagerstown loam	20.8	1.4	2.1	3.4	3.4	6.8	12.4	57.2	14.9
9248	Hagerstown loam	17.5	1.0	1.0	1.8	1.4	7.4	18.6	49.9	19.7
10212	Hagerstown silt loam	16.5	1.0	0.3	0.6	1.5	9.1	10.5	60.3	17.4
4983	Hagerstown shale loam	25.0	2.6	13.1	5.1	2.0	3.8	7.9	55.5	11.7
4962	Hagerstown clay loam	23.4	2.2	1.0	2.7	2.6	6.7	10.6	61.7	14.3
4966	Hagerstown clay loam	25.5	1.3	1.9	1.8	1.2	2.5	6.3	69.6	17.0
9037	Hagerstown clay	23.0	1.1	0.8	1.8	1.1	2.5	4.1	54.9	34.8
6024	Clarksville stony loam	13.7	0.3	1.5	2.1	1.2	3.2	8.0	67.9	16.5
6006	Clarksville loam	18.5	1.3	0.1	0.1	0.4	17.1	23.6	39.4	19.0
6018	Clarksville silt loam	15.1	1.2	1.2	1.4	0.9	2.9	5.6	73.2	14.8
6008	Clarksville clay loam	20.8	1.9	0.2	0.5	0.7	3.7	3.9	71.1	20.0
10184	Clarksville clay	31.7	2.3	0.4	0.9	0.5	1.2	4.5	54.0	37.7
6092	Miami sand	4.3	1.9	0.5	9.1	38.1	41.3	1.9	5.2	3.7
6696	Miami fine sand	4.7	1.1	0.3	17.4	26.0	35.6	10.3	5.9	4.5
9606	Miami sandy loam	7.0	2.1	3.4	11.8	15.0	33.2	14.7	14.4	7.3
9626	Miami fine sandy loam	13.3	1.7	1.6	5.1	7.8	25.4	15.2	32.3	12.4
8969	Miami stony loam	15.4	4.7	2.1	7.3	5.5	7.4	16.5	44.8	16.5
5008	Miami gravelly loam	13.4	0.8	5.6	11.4	9.5	18.0	15.9	26.1	13.2
5006	Miami loam	17.7	2.2	1.6	10.7	10.7	21.7	19.8	22.0	13.3
8506	Miami silt loam	18.5	0.9	0.3	1.2	0.8	1.2	6.4	79.6	16.7
5014	Miami clay loam	18.3	1.2	0.7	1.6	1.8	4.2	11.2	68.4	12.0
9505	Marshall sand	7.2	1.7	2.5	16.7	19.1	34.3	6.8	10.6	10.2
8804	Marshall fine sand	5.4	1.3	0.6	2.2	7.7	57.8	21.5	4.2	5.9
8398	Marshall sandy loam	13.4	3.5	4.6	14.0	12.7	22.5	10.1	24.0	12.1
8418	Marshall gravelly loam	19.7	7.8	7.3	20.2	10.8	8.7	5.8	28.9	18.0
9458	Marshall stony loam	30.2	3.9	2.3	8.7	10.4	28.7	15.1	22.8	12.1
8788	Marshall loam	18.8	2.1	1.5	6.4	8.0	19.5	16.3	23.3	24.7
8728	Marshall silt loam	26.9	2.1	0.2	0.9	0.5	0.6	3.7	76.3	17.7
9493	Marshall clay loam	23.3	5.1	0.2	4.1	4.9	8.2	4.3	52.8	25.4
8453	Marshall clay	36.4	5.4	0.2	1.7	1.7	4.3	2.0	49.3	40.8
8664	Sioux sand	4.9	2.4	0.4	14.2	30.7	43.5	1.1	5.9	4.4
8670	Sioux sandy loam	13.8	3.3	0.6	13.6	16.1	20.4	9.7	28.1	12.5
9535	Sioux fine sandy loam	21.4	2.6	1.2	4.5	4.9	16.9	21.9	38.6	11.8
9174	Sioux clay	38.4	5.2	0.0	0.3	0.8	5.8	4.5	32.1	56.6
9288	Dunkirk gravelly loam	7.9	2.7	17.4	18.1	12.6	15.7	9.2	17.4	9.6
9296	Dunkirk sandy loam	10.5	2.2	0.8	3.4	3.9	42.7	26.1	13.0	9.8
9286	Dunkirk clay	37.8	3.7	0.9	1.8	1.2	5.3	5.9	31.6	53.1
9334	Oswego fine sandy loam	9.7	1.3	0.1	0.9	1.1	26.1	31.2	29.3	11.1
9332	Oswego loam	19.4	2.7	0.7	1.8	0.8	3.6	15.8	61.1	16.2
9340	Oswego silt loam	11.3	1.2	0.3	0.4	0.3	1.9	9.6	74.1	13.2
6921	Sedgwick sandy loam	7.9	1.3	0.3	8.9	18.6	32.3	18.6	14.0	7.0
6909	Sedgwick loam	15.4	2.3	0.3	5.3	9.6	12.2	11.7	51.4	9.4
6917	Sedgwick clay loam	21.9	1.0	0.1	1.5	2.3	5.3	10.4	66.0	14.2
6919	Sedgwick black clay loam	15.2	1.3	0.3	1.0	1.3	8.3	31.2	48.6	9.1
7978	Memphis silt loam	12.9	1.2	0.3	0.8	0.6	0.7	2.9	83.8	10.6
6632	Delavan silt loam	25.6	2.9	0.3	0.9	0.7	1.0	8.9	69.4	18.8
7008	Marion silt loam	14.7	1.7	0.1	1.0	0.7	0.7	3.0	82.9	11.5
7009	Marion silt loam	14.7	0.7	1.1	1.8	1.0	1.1	3.5	79.8	11.8
7385	Waverly silt loam	24.4	2.0	0.7	2.6	1.1	2.7	7.6	62.9	22.2
4445	Maricopa gravelly loam	8.9	0.2	11.3	11.0	12.0	15.0	28.4	16.6	5.7
4494	Maricopa sandy loam	13.8	3.0	Tr.	2.3	15.0	27.7	28.2	13.5	13.0
8134	Maricopa silt loam	36.2	1.1	0.0	0.1	0.1	0.9	2.1	73.0	23.8
4486	Maricopa clay	19.1	0.4	1.3	4.0	10.2	19.1	23.1	19.4	22.8
4887	Fresno sand	3.0	0.4	0.9	15.8	31.3	22.6	18.1	8.2	3.0
4683	Fresno sandy loam	5.3	0.5	Tr.	1.0	3.9	23.5	31.7	32.9	7.0
5081	Fresno fine sandy loam	12.8	0.6	Tr.	3.0	3.8	16.9	35.4	36.3	4.7
5790	Yakima sand	5.4	0.3	0.3	1.5	9.6	38.9	40.6	5.8	3.1
7690	Yakima fine sand	10.6	0.8	0.2	2.2	5.8	24.8	22.6	37.8	6.4
5364	Yakima sandy loam	13.4	0.7	0.9	3.3	7.3	23.0	22.9	33.2	9.2
7509	Yakima silt loam	23.6	2.3	0.5	0.8	0.6	1.8	7.2	81.3	7.5
9136	Yakima loam	16.2	1.7	Tr.	0.5	0.6	13.0	35.0	34.0	16.6
5325	Cecil clay (subsoil)	36.2	0.3	0.9	4.0	4.1	9.4	6.0	16.2	59.8
5762	Iredell clay loam (subsoil)	46.5	0.4	1.4	1.6	1.7	8.9	8.5	17.8	59.8

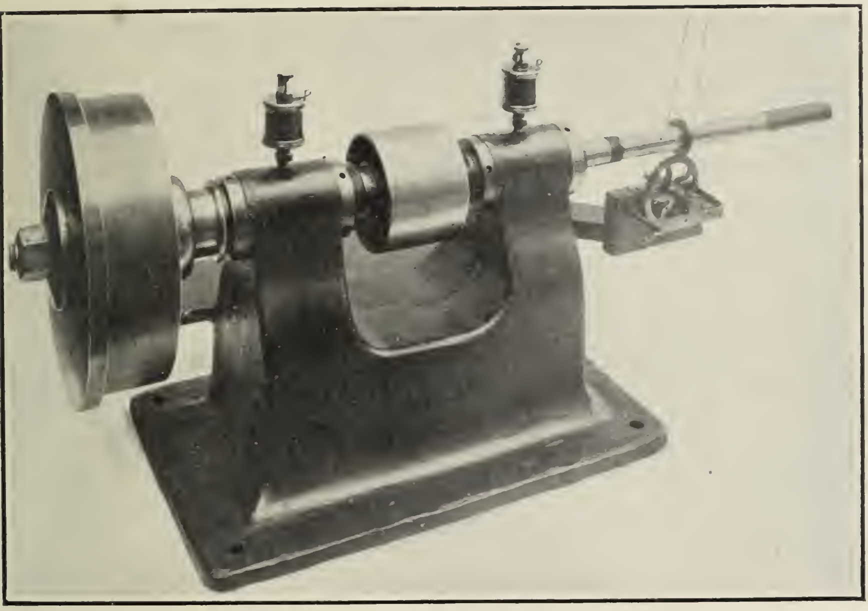

FIG. 1.—CENTRIFUGAL MACHINE USED FOR DETERMINING MOISTURE EQUIVALENTS.

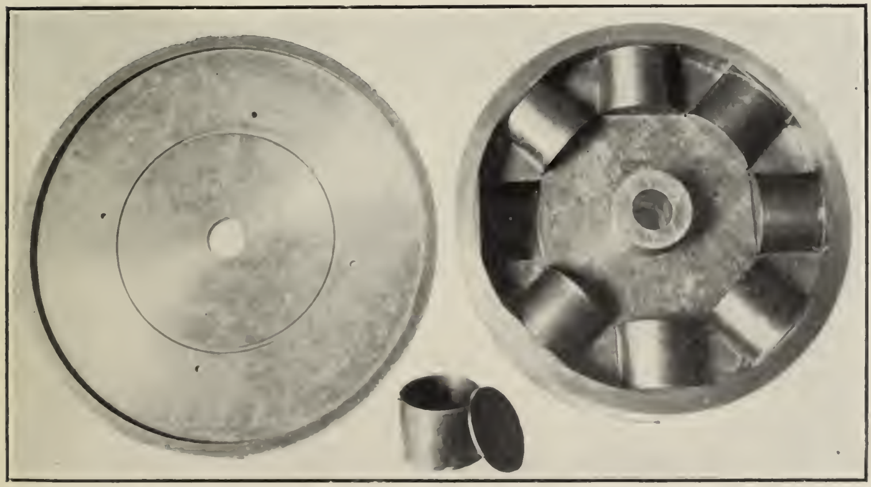

FIG. 2.—HEAD OF CENTRIFUGAL MACHINE, SHOWING CYLINDRICAL CUPS WITH PERFORATED BOTTOMS FOR HOLDING THE MOIST SAMPLES OF SOIL.

RELATION OF MECHANICAL COMPOSITION TO THE MOISTURE EQUIVALENT.

In order to determine whether a definite relation could be found between the mechanical composition of the soils and the moisture equivalents, the data given in Table VII were examined by the method of least squares. It was *assumed* that the sands, silt, clay, and organic matter all helped to hold the moisture in the soil, and it was further *assumed* that the retentive power of each constituent was directly proportional to the amount of that constituent present. The object was then to determine the moisture retentivities of the various constituents. The observational equations, in accordance with the above assumption, were of the form

$$\begin{array}{c} A_1 Z_1 + B_1 Z_2 + C_1 Z_3 + D_1 Z_4 + E_1 Z_5 = M_1, \\ A_2 Z_1 + B_2 Z_2 + C_2 Z_3 + D_2 Z_4 + E_2 Z_5 = M_2, \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ A_n Z_1 + B_n Z_2 + C_n Z_3 + D_n Z_4 + E_n Z_5 = M_n, \end{array} \qquad (1)$$

in which

A = per cent, groups 1, 2, 3 (2–0.25 mm.),
B = per cent, groups 4, 5 (0.25–0.05 mm.),
C = per cent, group 6 (0.05–0.005 mm.),
D = per cent, group 7 (0.005–0 mm.),
E = per cent, organic matter,
M = moisture equivalent.

and Z_1, Z_2, Z_3, Z_4, Z_5, were the unknown coefficients, whose values we wished to determine.

Each soil examined gave an observational equation of this form, amounting to 104 equations in all. Owing to the inherent differences in the *character* of the clay and of the organic matter as well as the observational errors, these equations could not be exactly satisfied by one set of values of the Z-coefficients. It was therefore necessary to determine by the method of least squares the most probable values of the Z-coefficients; that is, the best values that could be deduced from the given observations. The most probable values of the coefficients as determined from the 104 equations were:

$$\begin{array}{l} Z_1 = 0.022 \\ Z_2 = 0.002 \\ Z_3 = 0.130 \\ Z_4 = 0.622 \\ Z_5 = 0.627 \end{array}$$

The equation expressing the relation between the mechanical composition of a soil and its moisture equivalent, as determined from the 104 observational equations, would then be

$$0.022A + 0.002B + 0.13C + 0.622D + 0.627E = M. \qquad (2)$$

By substituting the above values of the Z-coefficients in each observational equation, we determined the difference between the observed and calculated values of the moisture equivalent in each case. From these residuals we calculated the probable error[a] of a single determination of the moisture equivalent by means of equation (2), which was found to be

$$r = \pm 3.1.$$

The equation expressing the relation between the moisture equivalent and the mechanical composition for the 104 soils becomes, when the probable error is included,

$$0.022A + 0.002B + 0.13C + 0.622D + 0.627E = M \pm 3.1. \quad (3)$$

According to this equation, equal quantities of organic matter and clay have nearly the same effect on the moisture equivalent. For the centrifugal force employed, the moisture equivalent, expressed in per cent, is proportional to about 0.62 of the total percentage of clay and organic matter together. The silt has only about one-fifth the effect of the clay and the organic matter, the moisture equivalent being proportional to 0.13 of the silt content. The coefficients of the sand groups are both very small, as we should expect. An anomaly arises, however, in the case of these two groups, the coarser sand having apparently a greater influence on the retention of moisture than the finer grades of sand. This results from the fact

[a] The term "probable error" is here used in its technical sense, and serves as a measure of the accuracy of the observations, in this case, of both the moisture equivalent and the mechanical composition. As here used, it includes also the *departures* due to the lack of uniformity in the character of the clay and organic matter in the different soils considered. The uncertainty resulting from this lack of uniformity would be more properly expressed by the term "probable departure," since it is not due to the observational errors. However, it is not possible in a series of observations of this kind to separate these two terms, so that the term probable error has been used in this inclusive sense.

The term probable error should not be interpreted to mean "the most probable error," or "the most probable value of the actual error." In any series of errors, the probable error has such a value that the number of errors greater than it is the same as the number of errors less than it. In other words, the chances are even that an observation selected at random will have an error greater than or less than the probable error.

It should be emphasized that the probable error is concerned with errors of an accidental character—errors which are as likely to lead to results too large as to results too small. A single determination of the probable error can not reveal the existence of a constant error, nor show whether the assumption made regarding the relation between the observed quantities is correct. Errors of this kind must be detected by changing the form of the observational equation, and determining the probable error for each form of equation assumed. The form giving the smallest probable error most nearly represents the relation sought.

that the soils vary greatly in character, so that the individual peculiarities of the soils tend to mask the true values of coefficients that are very small.

The slight influence of the sand groups is shown by the fact that a change of 50 per cent in the amount of coarse sand amounts to a change of but 1 per cent in the moisture equivalent. We can consequently ignore the influence of the sands in an approximate equation, whence equation (3) becomes,

$$0.13C + 0.62(D+E) = M \pm 3. \qquad (4)$$

NORFOLK AND PORTSMOUTH SERIES.

In the case of a well-defined series of soils in which the material is mainly derived from the same source one would expect a more definite relation between the mechanical composition and the moisture equivalent than would be the case for soils derived from different rocks under widely varying conditions. We have accordingly determined by the method of the least squares the coefficients for the Norfolk and Portsmouth series combined, which are quite similar in character, save that the Portsmouth includes heavier soils and carries more organic matter. The coefficients of the sands were taken equal to zero, and for the other coefficients the following values were obtained:

$$Z_3 = 0.042$$
$$Z_4 = 0.590$$
$$Z_5 = 0.528$$

The equation of the combined Norfolk and Portsmouth series is then

$$0.04C + 0.59D + 0.53E = M \qquad (5)$$

A comparison of the observed moisture equivalents with those calculated with the aid of equation (4) is given in the following table:

TABLE VIII.—*Comparison of observed and calculated moisture equivalents of the Norfolk and Portsmouth series.*

Sample number	C (0.05–0.005).	D (0.005–0.0).	E Organic matter.	Moisture equivalent. Calculated.	Observed.	Residuals.
9107	7	5	0.9	3.7	4.6	−0.9
8522	7	6	1.0	4.4	3.6	+0.8
8589	8	3	.8	2.5	3.8	−1.3
5665	19	5	7	4.1	6.5	−2.4
8706	18	8	1.3	6.2	6.8	−0.6
8682	42	10	1.9	8.7	7.7	+1.0
5493	68	12	1.2	10.6	11.1	−0.5
8530	7	11	3.0	8.3	7.1	+1.2
10666	24	13	1.0	9.2	11.8	−2.6
8022	44	17	2.7	13.3	10.6	+2.7
8537	24	19	10.9	18.0	18.6	−0.6

From the residuals in Table VIII we can calculate the probable error of a single determination, which we find to be

$$r=1.09$$

which means that if the soils employed in the measurements were typical, then the chances are even that the moisture equivalent of any other typical soil can be determined from equation (5) within 1.1 of its absolute value. The characteristic equation of the combined Norfolk and Portsmouth series then becomes

$$0.04C+0.59D+0.53E=M\pm 1.1 \qquad (6)$$

Comparing this equation with equation (4), we see that the ratio of the probable errors is 1:2.7. In other words, equation (6) expresses the relation between the mechanical composition and the moisture equivalent for the Norfolk and Portsmouth series with an accuracy 2.7 times that of the equation (4) for the 104 soils. The coefficients for the Norfolk and Portsmouth series are all smaller than in equation (4), the organic matter coefficient being reduced from 0.63 to 0.53, the coefficient for the clay group from 0.62 to 0.59, while the greatest change occurs in the silt group, which is reduced from 0.13 to 0.04.

MARSHALL SERIES.

For the Marshall series, omitting samples 8418 and 9158, which are said not to be typical, the following values of the Z coefficients were obtained:

$$Z_3=\ \ 0.20$$
$$Z_4=\ \ 0.62$$
$$Z_5=-0.11$$

The equation for the Marshall series is then

$$0.20C+0.62D-0.11E=M \qquad (7)$$

A comparison of the observed moisture equivalents with those calculated from equation (7) is given in Table IX.

TABLE IX.—*Comparison of the observed and calculated moisture equivalents of the Marshall series.*

Sample number.	C (0.05–0.005).	D (0.005–0.0).	E organic matter.	Moisture equivalent. Calculated.	Observed.	Residuals.
9505	11	10	1.7	8.2	7.2	+1.0
8804	4	6	1.3	4.4	5.4	−1.0
8398	24	12	3.5	11.8	13.4	−1.6
8788	23	25	2.1	19.8	18.8	+1.0
8728	76	18	2.1	26.1	26.9	−0.8
9493	53	25	5.1	25.5	23.3	+2.2
8453	49	41	5.4	34.6	36.4	−1.8

For this series the probable error in the calculation of the moisture equivalent of a typical sample from its mechanical analysis is

$$r=1.04$$

which is slightly less than the probable error for the Norfolk and Portsmouth series.

The equation of the Marshall series then becomes

$$0.20C+0.62D-0.11E=M+1.0 \tag{8}$$

MOISTURE EQUIVALENT COEFFICIENTS OF CECIL, HAGERSTOWN, MIAMI, AND VERNON SERIES.

In Table X the coefficients given above are summarized, together with the results of a number of calculations made in different ways upon other soil types. In the Cecil series, for example, the coefficients have been determined: (1) for the silt, and for the clay and organic matter combined; (2) for the silt, clay, and organic matter separated; (3) for the clay and organic matter, assuming that the silt and coarser grades have no effect on the moisture equivalent.

TABLE X.—*Summary of moisture equivalent coefficients.*

Series.	Silt.	Clay.	Organic matter.	Clay + organic matter.	Probable error, moisture equivalent.
All	0.13	0.62	0.63		3.1
Norfolk and Portsmouth	.04	.59	.53		1.1
Marshall	.20	.62	.11		1.0
Cecil	.03			0.62	1.7
Do	.06	.39	3.6		1.2
Do		.44	3.6		.7
Hagerstown	.35			.06	2.4
Do	.25	.11	2.4		2.0
Do		.61	4.7		3.2
Miami	.09			.69	2.2
Do		.70	1.8		2.7
Vernon	.17			.74	.8
Do		1.4	.002		2.4

According to these results, the moisture equivalents of the Cecil series could best be expressed in terms of the mechanical analysis by considering only the clay and organic matter, since on this assumption we obtain the smallest probable error. This illustrates the danger of generalizing from a small number of observations in a question of this kind, since no one would admit the effect of the silt to be nil. It will be noticed, also, that in all other instances we get the highest probable error on this assumption. The danger just spoken of is especially well illustrated in the Hagerstown series, where the reductions would indicate that the clay had less effect than the silt in the retention of moisture. This relation is altogether improbable, and undoubtedly would not appear in the reductions if

a suitable number of samples were considered. With this precaution, this method of reduction could be used to determine to what extent one series differs from another in the relation of its silt, clay, and organic matter to the retention of moisture. This would, however, resolve itself into a special study of the characteristics of the different series. The present reductions emphasize the individuality of different soils.

SUMMARY.

In the comparative study of soils it is important to supplement the mechanical analyses by quantitative measurements of other characters, especially those relating to the movement and retention of moisture.

The present paper deals with a method of determining the amount of water which different soils are capable of retaining when the soil moisture is subjected to a constant measured force sufficient in magnitude to remove the moisture from the larger capillary spaces. The method is as follows: The soils under investigation are first thoroughly moistened, and are then placed in the perforated cups of a centrifugal machine, where they are subjected to a constant centrifugal force until they cease to lose moisture. The percentage of water remaining in the soil is then determined.

It is possible to reduce the moisture content of a soil in this way so that it is no greater than the moisture content of the soil under favorable field conditions. By this method, then, it is possible to determine the retentive power of different soils for moisture when acted upon by the same definite force, comparable in magnitude with the pulling force to which the soil moisture is subjected in the field. Furthermore, this method of comparing the relation of soils to moisture avoids to a large extent, if not entirely, the errors due to differences in packing, since the soils are packed by centrifugal force, which acts upon each individual particle. This is further safeguarded by the high speed employed, which is sufficient to remove the moisture from any large capillary spaces that may possibly be formed.

The method has the further advantage that the force employed can be accurately determined by measuring the radius of rotation and the speed of the machine. A wide range in the force used can also be easily secured simply by changing the speed of the machine, since the centrifugal force increases as the square of the speed.

The maximum percentage of moisture which a soil can retain when in equilibrium with a definite force we have designated as the "moisture equivalent" of that soil for the particular force employed. It logically follows that a series of soils which have thus been brought

into equilibrium with the same force will be in capillary equilibrium with one another when brought into contact, and that no capillary movement of moisture will take place between them. In other words, the moisture equivalents of a series of soils represent the moisture contents which those soils must have in order to make it equally difficult to remove a very small additional amount of moisture from any of the soils. It is from this point of view that the determination of the moisture equivalent becomes of especial importance in the comparison of the moisture contents of different soils under growing crops.

The moisture equivalents of over 100 samples of type soils have been determined, employing for this purpose a centrifugal force about 3,000 times the force of gravity. These moisture equivalents vary from 3.6 per cent in the coarser sandy soils to 46.5 per cent in the case of a heavy clay subsoil.

These observations were reduced by the method of least squares to determine the influence of the sand, silt, and clay groups, and of the organic matter, upon the retention of moisture. It was found for the whole series that each per cent of clay or of organic matter in the soil corresponded to a retention of 0.62 per cent of moisture when the soil was subjected to a force 3,000 times that of gravity. Each per cent of silt, under similar conditions, corresponded to a retention of 0.13 per cent of moisture, and the coarser grades show practically no retentive action against this force. The "probable error" for these coefficients was rather high, and better results were obtained for smaller series of related soils, using a different set of coefficients. It is interesting to note that the organic matter, for the force employed, has a retentive power no greater than the clay group.

In investigating the influence of the speed upon the moisture equivalent it was found, for the series of soils examined, that between certain limits the amount of moisture set free when the pulling force is increased by a definite amount is the same for the different soils. In other words, when this series of moist soils is in equilibrium with a given force, and the force is then increased by a definite amount, the amount of water set free is independent of the initial water content. Within these limits, then, a sandy soil and a heavy soil of this series part with equal amounts of moisture.

O